3.3   A Critical Review of Emergency Evacuation Simulation Models

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The paper presents a critical review of selected simulation models including (1) flow based, (2) cellular automata, (3) agent-based, and (4) activity-based models, as well as of three simulation models that incorporate social scientific processes--FIRESCAP, EXODUS, and the Multi-Agent Simulation for Crisis Management. It concludes by pointing out the so far ignored insights that could be derived from the fields of social psychology and social organization. A number of predictions regarding the effects of social organizational variables on the timing and movement of evacuating groups are presented.

We offer a critical review of selected simulation models of evacuation behavior based on published descriptions of their characteristics rather than on empirical tests of their claims (compare to Kuligowski, 2003). A second section of the paper identifies social sciences approaches that could improve present day simulation models. Our argument is that the social sciences could provide important new directions to simulation models of emergency evacuations; to the extent that simulation models are attempting to incorporate actual human social behavior, a dialogue among engineers, computer scientists, fire scientists, and social scientists would render such models more accurate and realistic. So far, as we will show, the absence of this dialogue has impacted many of these models.

It is useful to think of evacuation behavior during emergencies, commonly referred to as emergency egress, as having three distinct analytical dimensions: the physical location of the evacuation (the environment and its configuration from which to evacuate, as well as the configuration of the hazard); the existing management of the location (the managerial policies, procedures, and controls deployed at evacuation); and the social psychological and social organizational characteristics impacting the response of persons and collectivities that participate in the evacuation. It is much more common in the literature to find consideration of the first two dimensions, as exemplified in Elliot and Smith's analysis of football stadia disasters in the United Kingdom (1993), than of the third, despite the fact that real advances in our understanding of emergency evacuations will depend on their holistic integration.

Traditions in the Study of Emergency Evacuation

One of these traditions focus on the physical, engineering dimensions impacting smoke control and the movement of people in buildings (Gwynne, Galea, Owens, Lawrence, 2000). It calls attention to the impact on evacuation movement of the presence and location of exit signs, position of exits, width and other conditions of stairs. Increasingly, it also recognizes the importance of emergency training and the existence of programs of exercises, drills, constant monitoring of safety in buildings (Pauls, 1978), and appropriate building code legislation

(Jennings, 2000). A key part of this tradition is evacuation simulation models. Such models have burgeoned, a development that demands particular attention to the needed inclusion of insights from the social scientific literature as they pertain to group integration and emergent group processes. We next review a single model from some of the most widely known simulation methods, including (1) flow based, (2) cellular automata, and (3) agent-based models. We also examine three models that incorporated social dimensions, the FIRESCAP, EXODUS, and Multi-Agent Simulation for Crisis Management.

Flow-Based Modeling

EVACNET4. The EVACNET4 model employs a flow-based approach that models the density of nodes in continuous flows (Kisko, Francis, and Nobel, 1998). EVACNET4 enables the user to construct a simulated physical environment *as a network of nodes*. The nodes represent physical structures, such as rooms, stairs, lobbies, and hallways that are all connected and comprise a single structure from which an evacuation is executed. The user defines the "contents" of the all nodes-as-network, a step that involves the determination of how many people the particular node may contain. Certain nodes are designated as "destination nodes," thus identifying all of the possible terminal points of occupant egress. For each node, the usable area (UA) must be calculated and allowance is made for the presence of closets, equipment, and other such items, as well as the space which persons place between themselves and a wall. This latter feature entails the inward projection of each node wall by 6 inches. Besides nodes, the model also requires the provision of specification for arcs. Arcs are passageways between building components. The user must supply a "traversal time," or the amount of time periods it takes to cross the passageway, and an "arc flow capacity," which delimits the amount of human occupants that can traverse the passageway per time period.

In terms of human occupants, the node capacities are directly linked to the "queuing level of service (LOS)" (pg. 23). The LOS offers a set of parameters grouped in a range from A to F that define the average pedestrian area occupancy, the average inter-person spacing, and a brief qualitative description of conditions as evacuees would experience them. For example, Queuing Level of Service "A" posits 13 sq. ft. of average pedestrian occupancy and 4ft. of inter-person spacing, which in practice corresponds to "standing and free circulation through the queuing area is possible without disturbing others within the queue" (*ibid*). Level of Service "E" delineates the most "extreme" evacuation conditions in which persons are in direct physical contact with others around them, no movement is possible within the queue, and *"the potential for panic exists"* (pg. 24). This brief allusion to panic will receive more attention below. For purposes of the simulation, the user divides the usable floor space by the area occupancy level to generate a tentative node capacity. The only other factor that would alter this figure is accounting for the ratio of allowable hallway floor loading to average weight of an occupant.

The arc capacities are determined on the basis of information derived from another set of service classifications, very similar to those associated with node capacities, called "Walkway Level of Service" and "Stairway Level of Service" (25, 27). These also provide a set of parameters that define average flow volume, average speed, and average pedestrian area occupancy. These calculations relate to hallways, stairwells, doors, and escalators. The average speeds assigned to each stairway LOS are based on the research of Fruin (1970, 1971), which assumes two separate

sets of measurements for an indoor stairway and an outdoor stairway. The assumed indoor stair has a 7-inch rise (17.8 cm), 11.25-inch (28.6cm) tread, and 32-degree angle. The outdoor stair has a 6-inch rise (15.24 cm), 12-inch (30.5 cm) tread, and 27-degree angle. In developing the general model attributes as they relate to stairwells, the authors relied heavily upon Jake Pauls' (1978, 1980) flow model (22). Finally, with respect to arc definitions and data, the Width Restriction (WR) associated with each arc, usually a doorway that stands between the nodes of an arc, determines the Dynamic Capacity of an arc. Determining the dynamic capacity involves multiplying the width restriction (WR) of an arc by its average flow volume (provided by the LOS) and then by the chosen time period. EVACNET4 provides the user, at the conclusion of these calculations, the option of viewing a list of all of the specifications associated with all the nodes and arcs of the constructed network model.

EVACNET4 takes the completed network model and determines an optimal plan to evacuate the building in a "minimum" amount of time. This is achieved using an advanced capacitated network flow transshipment algorithm, a specialized algorithm used in solving linear programming problems with network structure. The user is provided a summary of results for the specified model, including total time periods, congestion factor, average number of periods for an evacuee to evacuate, and number of successful evacuees. In EVACNET4 the egress of evacuees is determined almost entirely on the basis of physical constraints such as the usable area average, flow rates, and the particular configuration of nodes. It is designed to produce results that take account of a fixed set of environmental features, assumed travel speeds, and an arrangement of varying levels of service. No provision is made for motion rules that attend to social interaction or group processes. Like other models of this sort, most social interaction elements are rendered irrelevant or superfluous because evacuation times depend primarily upon node capacity and traversal times. The consequence is that several sociological assumptions can be made but not articulated or translated into attributes or algorithms relating to the motion of persons. Indeed, this model does not lend itself to agent modeling, for it makes the incorrect assumption of agent homogeneity. The only control the user may exercise "over persons" is in setting the preliminary contents of rooms, and perhaps in setting the travel speeds. Once again, however, this relies upon viewing the movement of evacuees as a continuous flow, not as an aggregate of persons varying in physical abilities, individual dispositions and direction of movement.

The absence of agent attribute specification eschews the need to consider the sociological aspects of group decision-making processes (see below) that inhere in all emergency evacuations. The prospect of more realistic results is impeded by the lack of consideration of the more emergent and variable aspects of evacuations—namely, the behavior of evacuees that together comprise a set of groups, each of which are characterized by varying levels of integration or conflict as well as different definitions of the situation. Flow-based models, such as EESCAPE and EGRESSPRO, bypass social factors because the simulation is couched on the assumption that if the user can manipulate walking speed, physical constraints in walkways and stairways, density, and distribution of persons across the building, then this is sufficient to estimate the *flow* of the process of evacuation without accounting for the social behavior of individual evacuees. (Kendik, 1995; Simenko, 2001).

Cellular Automata

EGRESS. The central difference between cellular automata modeling of evacuations and all other modeling types involves the discretization of space. This program discretizes space and models the node density in individual floor "cells." In EGRESS, the evacuees are modeled as "individuals" on a grid (AEA Technology, 2002). The grid is part of a plot plan designed by the user of the program. The program permits the testing of evacuation from a plot plan of any desired structure with metric dimensions of up to several square kilometers. The simulation technique of cellular automata frames the movement of an evacuee in this plot plan as a series of "time-steps," whereby the simulated person moves from cell to cell on the basis of a throw of a weighed die. Furthermore, "the weights required for the die are calibrated against information on speed, or flow, as a function of density, so that the experimental data can be adequately represented where it is valid" (*ibid*). Evacuees modeled within this program, then, are assumed to maintain a certain amount of space between themselves and other evacuees. The movement of the evacuee can also be compared to the progression of hazardous substances or smoke. The strength of EGRESS as a simulation program is found in its capability to execute this sort of comparative analysis an answer to the question of how the flow of toxic substances inhibit the timing and rate of egress. However, like several models reviewed in this paper, it is overly concerned with the tracking of the movement of an individual, not the social behavioral antecedents and processes that inform any single episode of egress. Other models to which the same comments may be applied are Pathfinder and TIMTEX.

The "magnetic model" of Okazaki and Matsushita (1993) illustrates the above-mentioned problem. It "equips" the individual occupant with certain specialized features pertaining to movement but not with calculations relating to social capacities. Each occupant has three different methods of walking (indicated route, shortest route, and wayfinding) and can join a group (http://www.anc-d.fukui-u.ac.jp/~sat/ECS93.pdf). The group-joining function, however, is not the result of an individual, or set of individual, probabilistic calculations rooted in conceptions of social interaction. Instead it is solely dependent on the size of the population: groups are formed only if the population grows to a certain size and then the group travels toward a common destination with the same start time, orientation, and method of walking (Okazaki and Matsushita, 1993: 6-10).

One of the problems with these models is that the culturally-appropriate norms regulating personal space break down in situations of crisis such as emergency evacuations, so that it is very difficult to know a priori what values to use for the setting of this parameter in the simulation models. Moreover, very often it is the case that to understand the initiation and speed of movement of the evacuee we must also understand the pattern of movement of his or her group. Thus, primacy must be placed in conceptualizing the evacuee as embedded in a web of social norms and in command of certain communicative abilities, making necessary to include in simulation models symbolic interaction processes and group decision making.

Agent-Based Modeling

SIMULEX. The SIMULEX Version 2.0 evacuation simulation program features an advance in the area of evacuation simulation software, for it "individualizes" the movement of groups. That is, it fixes a certain set of attributes to each "person," so that "the walking speed of each person is assessed independently of the average density of a group in a defined area" (Thompson and Marchant, 1995: pg. 132). As Thompson and Marchant indicate, the model allows *each person* to decide upon his or her own walking speed. Beyond this improvement, the program also takes several other factors into account, which are included in the derivation of motion algorithms. It includes several factors such as physical motions and gestures (body swaying and twisting), the proximity of other evacuees, the shape of the building structure, and the influence of sex (male or female) and age (parameters defined for persons 12-55 years old) that are said to have social significance but that are not based upon concepts or information about social relations, culture, or group integration. Instead, the program assumes the presence of a rational agent able to assess the optimal escape route and the agent's ability to avoid physical obstruction and "overtake" other persons that are conceptualized as impediments to movement.

During the preparation phase in which the density of the population is determined (and then entered into SIMULEX), it is mentioned that "a grid of occupants, with regular spacing between each person is then located within available space of the populated area" (pg. 138). The use of the term "regular spacing" is apparently based on research findings (perhaps from Ando *et al.* or Bryan), but it is not clear from whom the figure is derived or whether they could be adjusted for "seasonal differences." That is, as Pauls (1975) has shown in various reports, the wearing of heavy winter clothing as opposed to light, casual wear influences walking speed and hence any basic assessment of personal space. Moreover, as a number of studies in the sociology of collective behavior have demonstrated, people are very seldom if ever evenly spaced in public areas. Rather the typical configuration of people distributed in space in gatherings in public areas is that of the small group in circles and semi circles, which would be a much more preferable assumption than regular spacing.

The authors indicate that the evacuation simulation consists of a "series of repeated analytical loops…at each time-step, the position and attributes of each individual are retrieved…[and] the processing for the whole population occurs sequentially in the order of the person nearest to exit first, to the person furthest from the exit, last" (pg. 142). Do these analytical loops entail that as the program is working out the motion of a person, say, five meters from the exit (which it will do first), there is "nothing" occurring with a person that is 20 meters away and perhaps still in a room, that is, not until the "cycle comes back" to him or her. If it does, then this procedure ignores the fact that gatherings of people in evacuations are more appropriately conceptualized not as the sum of disaggregated sections but as totalities experiencing dynamic processes. As such, communication is often impeded from front to back to front of the gathering (Johnson, 1987), with attending misunderstandings as people try to move towards exits. It is also the case that people in a gathering are not uniformly motivated to participate in the central theme of the gathering, so that often the people to the front of the gathering before the crisis materializes, or those closest to where the action is, have greater commitment to the event that is taking place; they may be self selected on the basis of age, marital status, gender, and other characteristics that

will have an impact on their evacuation behavior as they respond to the crisis (Seidler, Meyer and Mac Gillivray, 1976).

Sequential processing also raises other problems. There are many cases in which widely differing conduct is occurring simultaneously during an evacuation. For example, individual persons may be exiting a building at one location while at another spot there is a group of persons considering how to help an elderly person travel through the corridors. A general movement of all persons toward building exits at all times is not typical, even if varying in flow speed at different locations. Some research has demonstrated that in many instances there may be a "front-to-back-to-front" dynamic in evacuation movement. Johnson *et al.* (1994) identified the reentry of evacuees or reversal of motion among evacuees who were concerned with the well being of unaccounted group members that remained within the Beverly Hills club. In his study of the 'stampede' at "The Who" concert, Johnson (1987) also found that those at the back trying to enter the auditorium were largely unaware of what was happening at the front of the gathering, as the huddled mass near the front gate desperately tried to survive the crush. The mutual ignorance of each segment of the gathering contributed to an unfortunate situation whereby the group attempting to escape the crushing effect clashed with the group trying to enter the building. The police's initial misunderstanding of what was happening, so that instead of opening the gates to let people into the building they kept them closed, aggravating the problem. The general insight to which this study contributes is that different people and groups in different areas may have markedly divergent views of the on-going situation. The last comment above leads to the most important set of recommendations and questions related to SIMULEX. Is it possible to apply motion algorithms to incorporate spatial-temporal and social characteristics of interactive processes that are associated with the emergence of norms and new definitions of the situation? This goal would involve the incorporation into the model of processes of social interaction such as milling and key-noting impacted, as Weller and Quarantelli suggested (1973), by pre-established and emergent social relations, and pre-established and new or emergent norms—rules for conduct.

To a limited extent, the program (Version 2.0) accounts for size of the group, potential physical incapacity, and visibility. We are not certain if it incorporates the effect of major physical disability and the subjective elements involved in recognizing signs of danger (see below). In terms of the first, perhaps calculations related to persons that are portrayed in the simulation as nearest to the source of fire or harmful substances could be adjusted for a range of severity of injury or probability of injury. In terms of the second, environmental features must be available to sensory perception before they can be interpreted as dangerous. The subjective availability and interpretation of the environment comes before the formation of a subjective awareness of danger. Thus, some adjustment must be made in the simulation model for movement from one spatial block to another when one block contains persons cognizant of an extreme threat and in collective agreement of the threat as opposed to persons in another block who are monitoring the environment but who have not developed the cognition or the collective awareness, or even people who cannot monitor the environment and have no possibility of developing an awareness of the threat. It is also the case that even if subjective understanding of danger exists in an individual, it may not be enough to cause his or her evacuation behavior, for other social organizational considerations may militate against it, such as group consensus regarding the

inappropriateness of the evacuation response, or subcultures that discount the message and the severity of the possible effects.

The social scientific literature attests to the importance of social control (evacuation management personnel) agents in emergency evacuations. Yet SIMULEX does not appear (at least in the 2.0 and 3.0 versions) to address the function of social control systems even though they often provide important information and constraints. How can their issuing of warnings or directions for movement be integrated into the simulation? Later on we address the problem of leadership. The testing of the SIMULEX model within the Superstore building points to the potential problem of intra-group and inter-group conflict surrounding the appropriate definition of the situation (see below), that is to say, there may be various sub-groups, some comprised of persons who are quite cohesive (maybe even kin), each of which are proceeding through a building only to confront other groups at a particular juncture in the building. Depending on the social characteristics and emergent practices (agreed upon definitions) assumed by each group, various consequences might ensue once they start interacting with each other and exchange information. The presence and uniformity of social control agents and the dissemination of evacuation directions may further modify the outcome of these interactions. Different building and settings and occasions will have different mixes of groups. It is reasonable to assume that different proportions of strangers, kin, and workmates characterize the groups in a gathering of a Fourth of July celebration as opposed to a non-holiday shopping day at the Superstore. The pre-existing and emergent normative agreement in each group as well as the probable distribution of stable and emergent group characteristics must be gauged differently from one type of gathering to another. The model may also have to allow for the inclusion of more features of the physical building during the DRAWPLAN phase. For example, certain room fixtures, furniture, and other devices may serve as *resources* for a group facing fire-related threats.

The EXIT89 model has the same sort of shortcomings as SIMULEX, in terms of social interaction and emergent group response. EXIT89 includes individual bodily dimensions (American, Soviet, or Austrian) and allows the specification of the number of disabled occupants, yet it does not incorporate bodily actions and gestures (Fahy, 1999). It also considers the counter-response of evacuees whose path during egress is blocked by smoke accumulation near an exit. The model determines travel time as a function of density and speed within a constructed network of nodes and arcs. The "shortest route" algorithm is combined with an individual perspective for each evacuee to track the path and progress of individual evacuees (Fahy, 1996; 1999). However, all the occupants of a certain node will initially traverse the same user-specified path, or shortest known path, to an exit. Moreover, the user is also able to set the percentage of occupants who will be assigned a delay time. These dual functions (a particular path for an entire group and delay) mimic group behavior in an implicit manner. A major drawback persists: individually tracked evacuees, although carriers of particular physical characteristics that affect the flow of evacuation, are devoid of social interactive characteristics such as monitoring others, directing, collective evaluation and collective agreement on appropriate response. The implicit inclusion of group behavior is not an ideal solution, for social interaction processes that feed emergent group processes are a crucial element in the understanding of all evacuations. The manner in which persons pursuing coordinated action relate to one another must be examined, for it will result in more diverse evacuation results and increased complexity of social action among evacuees.

In conclusion, SIMULEX does not incorporate group level processes. The review of the agent based models (i.e. SIMULEX, EXIT89, GridFlow) and flow-based models lead to the conclusion that neither the fluid mass nor the atomized individual within or without a group should be the sole referent for evacuation simulation models and research. Even though a plethora of socially relevant factors can be included in a model and will play an influential role on evacuation rates—such as in ALLSAFE, which includes individual level of alertness, social role, social affiliation, and visual perception—none of these can serve as substitutes for association or social interaction (Heskestad and Meland, 1998).

Models Incorporating Sociological Factors.

Exodus. In comparison to other models that incorporate sociological insights, the EXODUS simulation program furnishes perhaps the most complete set of social psychological attributes and characteristics for each agent, twenty-two in all. This set includes age, name, sex, breathing rate, running speed, dead/alive, among others. The agents in EXODUS also possess a fixed degree of familiarity with the building, agility, and patience. The model simulates the egress of large numbers of persons from an enclosure, but also accounts for the eventual cessation or delay of movement due to extreme heat or effect of toxic gases. The general model has been developed into different versions that vary according to several different contexts in which evacuations may occur, including ships (maritimeEXODUS), planes (airEXODUS), and buildings (buildingEXODUS).

As a primarily agent-based model, the movement of individuals in EXODUS is established by a fixed set of motion rules. The model as a whole is comprised of five interacting sub models: movement, behavior, passenger (agent), hazard, and toxicity. For instance, the hazard model will generate values that correspond to a particular configuration of threat across the simulated environment. The toxicity model determines levels of exposure to toxic substances, which then affects the values of the variables associated with agent behavior, which in turn influences the calculations of the movement model.

Owen *et al.* have demonstrated the prospective contributions of this model toward the prediction of evacuation performance and realistic modeling of social behavior. EXODUS features, for instance, an "itinerary list" (thus introducing an activity-based element) whereby each individual evacuee performs a certain amount of tasks *before* exiting the building. The potential actions on the itinerary are manifold, such as returning to a location to pick up a purse, performing a task in compliance with safety-related instruction, or even searching for a lost child. This latter capability speaks directly to numerous empirical findings. EXODUS also contains a feature that enables the use of signage, enabling evacuees to communicate through gestures during the way finding period (Filippidis *et al.* 2003). The aforementioned features, in combination with other rather unique functions such as a sub-model that measures the impact of irritant products and two parameters that enable evacuees to avoid congestion during general movement and congestion at exits, mark the EXODUS evacuation model as one of the most comprehensive (along with CRISP, a model from the UK) in terms of the inclusion of multi-dimensional factors that affect decision-making during evacuation.

EXODUS rightly directs attention to the potential need of conflict resolution during an evacuation. This behavior rule is probabilistically determined—that is, it will simply occur or not occur and hence is not reducible to smaller-scale interactions between agents. Parallel to several other models, the behavior sub-model in EXODUS determines the actions of evacuees to the "current prevailing situation on the basis of personal attributes."

EXODUS is one of a group of models that have accumulated an impressive constellation of factors that inform a more realistic evacuation scenarios. For instance, the ASERI model allows for the establishment of parameters such as age, sex, fitness, and special knowledge of the building. It also enables the evacuee to "seek for information" about the precipitating event and "inform others." This form of social interdependence, though modeled in ASERI in a very limited fashion, is crucial to any simulation program. Furthermore, the agent or evacuee can be allocated a "prepare" time in order to get dressed if sleeping during initiation of the threat or to fulfill other tasks before evacuating (Schneider, 2001). Similarly, CRISP3 provides for the capability of entering the social role and occupational data for an entire population, as well as probability calculations that determine a multiplicity of additional actions on the part of firefighters and evacuees, such as searching rooms, investigating, and even completing work (Fraser-Mitchell, 2001).

To be sure, EXODUS (and similar models) allows input from sub-models relating to the environment (toxicity) and the physical structure to alter certain behaviors that are pre-defined as not fixed, such as agility and mobility. However, as with the other models included in this analysis, there is a lack of micro-level mechanisms (probabilistic or otherwise) or other heuristics by which robust interaction within a group can generate emergent behaviors during emergency evacuation. More specifically, the EXODUS model, along with ASERI and CRISP3, do not integrate a vast catalogue of rules and probability functions that move the agent through different micro-level interactions with other agents and that (1) vary in level of social integration (for example, stranger, work associate, friend, family member) and (2) compel the agent to engage in a series of relatively quick yet sophisticated exchanges that create a collective definition of the situation for the group. Of course, an EXODUS user may direct an agent or group of agents to retrieve some item before exiting a building—but, this ability does not make a distinction between the imposition of this action upon individual entities within the program, on the one hand, and the emergence of this action as an outcome of several interactive exchanges, on the other hand. The latter option would infuse the evacuation simulation with increased social realism, for it would require highly nuanced construction of social behavioral rules that would focus attention on matters of leadership, the effects of social integration and cohesion, and the exchange of ideas among evacuees about possible courses of action (http://fseg.gre.ac.uk/fire/news.html#exodus_news). This last point is worth stressing, for members of groups involved in evacuation have personal histories, skills, and other attributes that orient their interaction during the crisis and may eventually influence their willingness to follow the direction of the leader and the decisions the groups make.

Some simulation models do include a series of subroutines or sub-calculations for each evacuee that realistically simulates aspects of the decision-making process during emergency situations and provide the foundation for the inclusion of realistic social interaction. The model BFIRES (Stahl, 1982) involves the activation of two different sets of computer subroutines. One

simulates perception and information gathering, while the other set of subroutines simulates information processing and decision-making. This includes a subroutine that compels the evacuee to gain information from persons that occupy the same general space and another subroutine that informs the occupant on whether the group can agree on an exit route. Another subroutine, BYSTND, determines probabilistically if an occupant will ignore a disabled person (Stahl, 1982). Another set of subroutines determines whether an occupant will or will not close a door after use. Once again, however, this level of complexity is still couched at the individual level, so that group level processes are skewed, such as the potential problem of lack of integration or conflicting perspectives.

Multi-Agent Simulation for Crisis Management (MASCM). This model improves upon other simulation models that are concerned with numerical analyses of inputs or amounts of people and structures. Murakami et al. rightly assert that the presence of evacuation leaders and the functions they serve during evacuation must be included in order to improve the validity of existing simulation models. The chief rationale for the inclusion of leaders is the expectation that they are key players in a variety of scenarios, which includes police officers, firefighters, security guards, and ushers. Indeed, Murakami et al. recognize the same set of criticisms that have been presented above, and thus aim to overcome the assumptions that permeate "traditional" simulators, including group homogeneity, unidirectional movement, and insignificance of social interaction. These researchers posit the pivotal role of leaders, especially in relation to changes in evacuation route. This feature serves as a welcome improvement to programs that only allow the user to specify whether the occupants will follow the shortest path out of a structure or, alternatively, use a familiar route, but do not furnish the computational mechanisms necessary to address (1) the existence of a leader (i.e. EXIT89 High Rise Evacuation Model), and (2) the possibility that a leader may lead a group through a path that is neither the shortest nor the familiar path, but is the only available path considering the location of the fire or threat
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Murakami et al. develop a multi-agent system for crisis management that is grounded, as is the case with EXODUS, on empirical data taken from "real-world" experiments (e.g. Sugiman, 1988). These experiments serve as benchmarks against which the data from the simulation is compared. Thus, they established a feedback loop between the model and the empirical evidence—although the independent confirmation of the validity of these claims is still missing. Prior to the development of the model the authors explored the impact of social interaction as simulated in 3D virtual spaces, which enabled the identification of the subtleties attending the interaction of evacuees and leaders in order to develop an accurate interaction language, called Q. This interaction language governs the operations of simulated agents created by two simple multi-agent systems, FreeWalk and FlatWalk. FreeWalk generates a 3-dimensional environment that produces agents that may interact with each other verbally and perform visual gestures, such as pointing. FlatWalk produces a two-dimensional "aerial" image whereby the entire group can be monitored during evacuation; what is more, the user can track the state of individual evacuees. It is precisely in its attention to the individual evacuee that this model produces significant improvements. It enables the user to develop a distinct scenario for each evacuee. A scenario, simply put, "determines the agent's response to his environment and peers" (Murakami et al., 2002) and depicts the flow of management events. Scenarios are combined with Rules, which is another interaction language construct that specifically governs the behavior of agents.

The rules set the parameters for agent behavior. This pair of language constructs, applied to the multi-agent systems of FlatWalk and FreeWalk, makes possible the introduction of "guarded commands" and other special forms of notation. These commands enable agents to wait for multiple events concurrently and observe the outside world while executing other actions. So, for example, a "guide agent" enters a "state of guidance" once he or she has received cues from the environment ("heard a siren"). According to the scenario set for this sort of agent, the simulated leader proceeds to "put on a cap" and enter the simulated environment. Once the "guide" agent "sees" an evacuee, he or she begins to guide the evacuee to a designated exit. These actions, in fulfillment of the pre-established scenario for that agent, can be part of a broader set of simultaneous actions. These include: (1) telling the evacuee to "Please follow me," (2) starting to walk along the evacuation route, (3) finding an evacuee at the distance, (4) waiting for the evacuee to approach and (5) listening to an evacuee speak. Actions (3), (4), and (5) represent the ability of the simulated agent to simultaneously monitor the outside world through cues and walk along the evacuation route. The untested assumption is that the evacuee thinks that the guides know what they are doing, can be heard and understood by the potential evacuees, can communicate their message effectively, and are trusted by the potential evacuees. Quite notably, Murakami et al. developed two sets of rules and scenarios for leaders: one set for the "Follow-direction Method" and another set for the "Follow-me Method." The authors chose to compare the evacuation times associated with each approach. The former involves verbally directing evacuees to an exit, while the latter involves physically leading evacuees to an exit without any appreciable verbal explanation of the route. In the scenario for the "Follow-direction Method, " the simulated leader is able to find those who are not moving and encourage them to do so, identify and verbally warn those who are headed in the wrong direction, and join a group of evacuees as they exit once it is determined that everyone is correctly evacuating. In the scenario for leaders using the "Follow-me Method," the leader likewise has various diverse capabilities, including the ability to identify the evacuee closest to him or her at the beginning of the egress period and lead them to the exit, to wait until those that have fallen behind recover before proceeding, and to look for another evacuee if one is lost during the guidance period.

Initially, the evacuees were controlled by the same set of rules regardless of the leadership method in use. The evacuees lacked a set of probability-based mechanisms that would represent a mode of internal information processing. That is, if the evacuee saw an exit, he or she proceeded towards it, and if he or she recognized a leader and received any type of direction to leave, such would be carried out without fail. However, after analyzing a video of actual human evacuees in a fire drill, the researchers decided that numerous alterations were warranted, all of which relate to important issues in the social scientific literature. First, some sort of delay had to be included in between the giving of direction and the decision to comply. Second, the simulation had to allow for the possibility of conflicting instructions from two or more leaders and for the potential denial of instruction if the evacuee noticed large numbers of people evacuating in a manner contrary to that instruction. The most relevant agent rules that were formulated to account for these modifications included the following: (1) disregard any instruction presented at the same time by two different leaders; (2) an evacuee does not move until the group around him moves; (3) an evacuee follows the evacuees around him or her; and (4) a given evacuee moves toward the group of evacuees who are in closest proximity.

There are two general shortcomings associated with the MASCM simulation model and the suggestive, yet limited, alterations made in response to the empirical data. First, although the presence and chief function of guide agents (leaders) is given fairly accurate and diverse applications, there is no set of mechanisms or calculations that furnish the possibility of simulating the set of group decision-making processes involved in selecting a leader when a "guide agent" or trained professional is not present. Yet it is often the case that in evacuation situations there are no official leaders. This sort of process is best exemplified in Johnson and Feinberg's model (1977) that incorporates "milling" and consensus formation in the selection of a group leader (see below). Moreover, the activities of an internally generated group leader will have an important impact on the ability of the guide agent or outside leaders to lead the evacuees. Neither possibility is considered in MASCM.

Second, despite the acknowledgement of potentially conflicting instructions and lack of uniform response, each agent in the MASCM model still makes the decision to exit without any "thick" affiliation to a primary group. To be sure, Murakami et al. recognize the importance of adherence to some group during evacuation, but fail to pinpoint the nature of the relationships between the persons and how these are likely to affect the rate and nature of evacuation behavior. For instance, the researchers developed a rule that directs an evacuee during egress to move toward the nearest group. However, studies by Johnson and Feinberg (1994), Aveni (1977), and others suggest that such an action typically involves various social factors including the character of the relationship between the evacuees and the groups of persons with whom they were before the precipitating event and crisis materialized and with whom they began evacuating. If the evacuees were with friends, work associates, and family members, and are separated from them during the course of egress, there are strong possibilities that the evacuees would search for those persons before fully exiting or would even return to the building after exiting. Thus, persons do not always gravitate to whatever group seems to be nearby—if they do, it is because their primary group was not present in the building to begin with or that it is difficult or impossible to do so.

FIRESCAP is a computer simulation model that implements a social theoretical formulation of "collective flight from a perceived threat" (Feinberg and Johnson, 1995; pg. 247). The entire model is couched in sociological terms and makes the following claims: (1) collective flight is a social event, which (2) is guided by "normative expectations and role demands" and (3) ensues only after information is sought after and ambiguous signs from the external environment are evaluated (*ibid*). The egress response, Feinberg and Johnson argue, is not instantaneous. Egress is the result of a socially structured decision making process guided by norms, roles, and role relations. Feinberg and Johnson base their assertions on their own extensive research of the Beverly Hills Club Fire of 1977 (1988, 1994) and on the research of Keating (1982), Quarantelli (1981), and others. Their review of the literature led to several additional assumptions that were then introduced into the evacuation simulation model. The authors assume that *ambiguity* is a chief feature of the initial phases of an evacuation, and thus give particular attention to agent-driven processes of creating a definition of the situation that accounts for several interrelated factors in the evacuation process. These include (1) the difference between perceived time available and perceived time needed, (2) the level of familiarity with the location of exits, (3) the ability to avoid congestion, and (4) the ability to take turns in the exiting process or seek an advantage for the self and primary-group members (pgs. 248, 249). Competitive behavior, however, is considered to be quite rare.

The computer simulation runs in TurboBasic, which is a deviation from the more typical use of C++ language in many other models reviewed here. Feinberg and Johnson posit fairly common physical constraints in relation to the number, width, and location of exits (pg. 251). Specifically, their simulation runs an episode of egress as occurring in a square room that has a maximum length of 20 meters on a side. The room is laid out as an invisible grid of locations, each of which is 1 square meter in area. During a fire, the maximum occupancy of a location is eight persons, whereas the limit is set at two persons when no threat is perceived. Persons in the program are either individuals or socially tied pairs who act in concert and whose bonds cannot be broken. The actors are assigned a randomly generated perception score (from .5 to 1.5) that determines the extent to which he or she is a fearful evacuee (willing to escape without visible cues of danger) or an "objective" evacuee that will attempt to thoroughly assess environmental cues. The model further maintains information on whether the evacuee is stationary, moving, or has exited.

FIRESCAP is based on a series of decisions that occur concurrently during each cycle. The decision to begin moving in response to an announcement of an emergency is made on the basis of a changing global probability that takes into account the degree to which a *visible* threat is evident and the perceived number of persons that are and are not moving (pg. 253). As these decisions are made, the statuses from the end of the preceding cycle are inserted into the new cycle and the physical threat level is updated. Moreover, the individuals (as opposed to the pairs) make their decisions alone and may even decide to evacuate almost immediately given a certain level of the "fearful disposition." The model functions in such a way that members of a pair may not have the same perception level and hence do not agree on the definition of the situation furnished by the two-fold criteria presented above. This disagreement is resolved through a probabilistic deference function. Hence, this model pioneers in simulating the matter of conflict within socially embedded social relationships. Competitive behavior (*regulated* pushing or overtaking) may occur under certain conditions between persons that are unknown to one another, and is based on an actor's perception of available time for exiting, the actor's "fear" value, and the level of competitiveness or cooperativeness among the persons in the surrounding vicinity.

The inclusion of a disposition such as fear or deference is not entirely without precedent. The E-SCAPE model determines the actions of occupants according to various Performance Shaping Factors (PSFs) and Hierarchical Task Analysis (Reisser-Weston, 1996: pg. 5). The PSFs include the organization of the work environment, certain emotional and social factors such as "deal with danger," the information available to the occupant, and the effect that certain tasks being carried out may have on evacuation. A hierarchical charting of tasks that must be carried out during evacuation complements the PSFs. Despite this inclusion of significant factors, the model only accounts for the impact of these factors by delaying the start- time of evacuation, not by actually carrying them out in the course of a simulated interaction.

In general, FIRESCAP implements a keen awareness of the multiple social criteria that persons assess before deciding to evacuate, the need for clear information about the situation and exits in order to avoid extensive ambiguity, and the significant yet somewhat fragile nature of orderly movement in the face of a major threat. However, the model disregards the use of models of

toxicity that also influence the choice of an exit route. FIRESCAP could clearly benefit from a set of specifications that generate more diverse and realistic physical environments. Also, the creation, presence and influence of leaders during evacuation is absent from this model, as is the recognition of the multiplicity of groups that may be present in the evacuation (see below).

The relative strengths and weaknesses of the models presented above (in varying detail) point toward several key recommendations. From a social science perspective, the ideal simulation modeling approach should seek the development of sub-models that posit an active, "investigative" socially embedded agent that assesses the state of other persons and forms a definition of the situation in cooperation with others. Furthermore, these agent-centered calculations should be placed in an on-going interaction between the properties of a particular fire and other hazard and the physical surroundings in which the evacuation takes place. Moreover, it would recognize that individuals evacuate in groups, and thus that group dynamics is an essential dimension that must be considered. The best overall theoretical approach for this task appears to be some version of emergent norm theory. The forthcoming section expands upon this claim.

The Reality of the Group

The previous pages have reviewed well-known simulation models of emergency evacuations and identified their strengths and shortcomings from the perspective of the social sciences of disasters, a perspective that helps us identify what or who evacuates in emergency evacuations. Individuals and groups are the constitutive units of emergency evacuations. They evacuate. To understand what they do in the evacuation, however, it is necessary to recognize that emergency evacuations are forms of collective behavior (see below) in which there are two major types of social behaviors, institutionalized behaviors and socio-cultural emergent behaviors (Aguirre, unpublished manuscript; compare to McPhail, 1991), the second often corresponding to mass behavior and crowds. There are also two distinct moments in emergency evacuations that impact on the safety of evacuees: their decision to begin evacuating, and their actual evacuation behavior. Both are important if we are to develop accurate simulations of emergency evacuations. Socio-psychological processes that we wish to examine impact both. Moreover, these two dynamic sets of behaviors occur in specific physical settings, which at the extreme erase the distinction among them.

It is useful to differentiate physical settings in which emergency evacuations take place along the following two dimensions: Does the space allow the simultaneous perception of danger? Settings differ in the extent to which all potential evacuees receive the same warning and have access to the presence or signs of danger. At the extreme, everyone in the gathering is in the same space, can hear and see others, receives the same warning signs and perceives the danger. The opposite situation occurs in setting in which people differ in the warnings they receive and the dangers they perceive. The second dimension is the human density of the space. Settings in which potential evacuees are co present, available to each other by sight and touch, and in which their density is very high, allow for the mass effect observed in many studies of emergency evacuation (Chertkoff and Kushigian, 1999, chapter 10), in which the response of the gathering of people to the perceived presence of danger and the sense of urgency to respond to the crisis is so immediate and overwhelming that the different propensities and choices of the individual

evacuee and his or her group are largely erased. People's responses become an important way in which other people in the gathering are warned. Instead, the individual becomes part of a mass of people moving towards the exits, and the sheer press of people eliminates most possibilities to determine his or her movement. At this extreme of mass behavior, often inappropriately called panic (Chertkoff and Kushigian, 1999), most potential evacuees and their groups do not have the opportunity to engage in decision-making regarding whether they should evacuate, with whom, when, and how. In these extreme circumstances the distinction between group and individual level emergency evacuation ceases to be meaningful. The safety engineering and architectural features of the space in which such mass behaviors take place, and the preparation and alertness of social control agents become the most important mechanisms impacting the successful outcomes of such evacuations. Social psychological and group level processes become much more important in other contexts in which this extreme mass behavior condition is absent, in settings in which all potential evacuees are not immediately available to each other visually and physically, in which there is much lower density, and in which there is variation in the warnings they receive and the signs of danger they perceive. Based on the foregoing, simulation models of emergency evacuations would do well in differentiating spaces in which evacuations take place in terms of these two ideal type sets of characteristics.

The shortcomings of the simulation models reviewed in the previous pages have in common the absence of the inclusion of relevant group level processes in evacuation simulation modeling. Most models lack an understanding of the social psychological and social organizational dimensions of emergency evacuations. While the lack of inclusion of social organizational features of emergency evacuation in these models is not surprising given the prevailing lack of interest in group level processes in the United States, the absence of social psychological processes is surprising, for the individual is usually perceived as the "real" actor in the United States and a good deal of social science research attention has been devoted to the individual actor, particularly to the study of individual threat perception and individual decision-making under crisis situations (Perry, 1978). Individual-level models of evacuation behavior (Sorensen, Vogt, Mileti, 1987) and evacuation decision-making by individuals (Perry et al., 1981, chapter 3) emphasize the importance of perceived threat (Sorensen, 1991, 157) and other factors that impact on individual's ability and willingness to act. Typical of this emphasis is the statement by Ikle and colleagues (1957) that the decision of the individual to leave a threatening situation depends on the degree of perceived threat, the motivation of these potential evacuees--- their withdrawal tendencies---and the factors that facilitate or impede their evacuation behavior, such as the perceived and or realized costs of evacuation.

Fortunately, at the social organizational level it has been possible to combine an emphasis on the social psychology of the actor (for an excellent review of this literature see Parks and Sanna, 1999) with an interest in macro features such as norms, values, status demands, leadership, division of labor and emergent generalized beliefs. Illustrative is Turner and Killian's (1987; see also Weller and Quarantelli, 1973; for a more recent version see Stott and Drury, 2000) emergent norm theory (ENT) of collective behavior. ENT is based on a symbolic interaction conceptualization of social life that emphasizes the importance of norms and social relations. It posits that nontraditional, collective behavior emerges from a normative crisis brought about by a precipitating event which, depending upon how the event is collectively perceived and interpreted by the participants, destroys, neutralizes, or no longer allows the pre existing

normative guidelines, division of labor, power, and other social arrangements to be collectively defined as appropriate guides for action to respond to the crisis. The crisis creates a sense of uncertainty and urgency forcing people to act, and participants are forced to create a new, emergent normative structure to guide their behavior in the crisis. They mill about as they attempt to define the situation, propose cues for appropriate action, evaluate their relevant skills in terms of the new demands of the situation, and try out alternate schemes to solve the problem. Forced by the crisis to abandon their previously established social relationships, statuses, and normative guidelines regarding legitimate ways of acting, people engage in collective behavior to solve the problems created by the crisis, in effect reconstituting their groups and pre existing social relationships. The theory assumes the presence of heterogeneous actors with different backgrounds, relevant skills, perceptual abilities, and motives about what is going on, what should be done to respond to the crisis, and who is responsible to do what and when. ENT assumes that collective behavior is not irrational but social, normative behavior.

Following E. Goffman's insights (1963; for an excellent review see Brown and Goldin, 1973, chapter 8), crises—what in Goffman's term are topics for focused interaction in encounters-- disrupt culturally specified occasions in specific physical settings. There is an occasion and the gathering of people enacting it. Such gatherings are composed of single individuals and of small groups. Then there is the crisis, the precipitating event that starts focused interaction in an encounter and the period of the emergency during which emergency evacuation takes place. For Goffman, interactions in these encounters are face-to-face, rich in meaning, revealing, rapidly changing, augmenting "attention to detail, an intensification of mutual dependence, and an absorption in the interactive moment" (Brown and Goldin, 1973, 154), with people moving about facilitating information dissemination. Goffman's theorization of the emergence of social organization in encounters can be reconciled to ENT, for he argues that encounters develop two types of norms that regulate them and permit their continuation through time and space. These are rules of irrelevance and of transformation. The first helps people engaged in reconstituting their groups to identify what is relevant and irrelevant about their situation, what they must attend to; the second help people incorporate into their social organizations extraneous items in such a way that the encounter is preserved (Brown and Goldin, 1973, 155-156).

Importantly for our present efforts, it is possible to derive from ENT and from Goffman's approach to social behavior in public a number of predictions for which there is some limited empirical support (Aguirre, Wenger, and Vigo, 1998). These are predictions in need of further testing and replication regarding the effects of social organizational variables on the timing of evacuation behavior that are nowadays mostly excluded from computer simulation models of emergency evacuations, for as we have tried to document, one of the near constants in simulation models of emergency evacuations is the near absence of consideration of group dynamics. This is the case even though people most often participate in public spaces in which emergency evacuations often take place in the company of significant others, in group contexts (Aveni, 1977). In this paper we extend these predictions to include the movement of evacuating collectivities.

Groups have four types of characteristics. One type is the context in which groups operate, such as the built environment. A second comes from the aggregation of the characteristics of the members of the group, for example their average age or average physical agility, as well as those

that are combinations of two or more aggregate characteristics, such as the group's sex ratio. The third type is illustrated by group density, which combines aggregate characteristic of the groups such as their sizes with contextual characteristics such as the physical space the groups occupy. A fourth type of group characteristics is created by relationships, both present and past, among the members of the group, for example, conceptions of statuses, leadership, group cohesiveness, division of labor, communication channels, power arrangements, and the myriad aspects of group culture such as language, cultural practices regarding personal space, traditions, dominant norms, and institutions such as law, regulatory agencies, political units. Many of these group characteristics must be included in simulation models, and research is needed to identify a parsimonious set of these characteristics that would be sufficient to make simulation models effective.

Aggregate characteristics of groups such as their size and heterogeneity should be important aspects of simulation models (Aguirre, Wenger and Vigo, 1998). The size of the group faced with a crisis is an important determinant of its timing of evacuation; the bigger the group the more difficult will be for the group to decide to evacuate as a response to the crisis, for it takes more time and effort for a large group to adopt the new behavior than for a smaller group; in the large group there will be more variation and differences of opinion and relevant experiences about what to do that must be reconciled before the emergent norm is created (compare to Kelley and Condry, 1965). Similarly, larger groups will move more slowly. Groups also have implications for the evacuation movement or flow, for they will tend to move in a block formation that will create an order to the evacuation flow, particularly if such flow takes place in stairways or other constrained spaces. In such situations, solo evacuees, or people who decide to evacuate on their own and join the flow, nevertheless come in contact with the blocks formed by these groups of evacuees and are regulated by them, for they are exposed to the set of norms and new statuses guiding the behavior of these collectivities which they cannot evade. The order and regulation that is very often observed in large evacuations from multi story buildings, such as the very successful evacuations from the WTC towers in the aftermath of the 9/11 terrorist attack, is generated by the presence and movement of these groups in the stairways, which is very similar to the order and regularity of traffic flows in situations of very high vehicular density, in which vehicles move at the same lower speed and reduce changing lanes (Helbing and Huberman, 1998).

Another important characteristic of groups is their heterogeneity in age, gender, social class, physical health and vigor, and relevant experiences. Research is needed to understand how group heterogeneity impacts the decision to evacuate and the evacuation behavior. Critical mass theory (Marwell and Oliver, 1993) would predict that groups with greater size and heterogeneity will be more likely to have members---who constitute the so-called critical mass---with the relative skills and resources needed to obtain the group's public good, namely surviving the hazard. Larger groups should have a greater probability of having a critical mass of able members. It can be derived from the theory that groups are mechanisms people use to attempt to survive the hazard. Not everyone in the gathering has the same skills and resources, so that that less-endowed members will benefit from the efforts of the stronger or more experienced members to bring about the escape, presumably a reason they keep with them. Moreover, it is immaterial to the strong and the more able how many others benefit from their actions in facilitating the group escape; what matters most to them is their own survival, not excluding

others from surviving. For non-mass behavior emergency evacuations, survival as a public good has jointness of supply, for the cost of providing it does not increase with the numbers of people who survive. Also, the usual crisis situations in which would be evacuees decide what to do are suffused with ambiguity, making it difficult to develop an accurate assessment as to whether defecting from the group will yield a higher probability of survival than staying with the group. Such evacuations are quite different from the widely discussed prisoner's dilemma (compare to Cornwell, 2003, 634).

Feelings of social solidarity, while not considered in critical mass theory, should also generate mutual assistance among the members of evacuating groups. It can be expected that the acts of members of the critical mass that benefit others in the evacuating group are not only the indirect results of their calculations of personal benefits but also come about intentionally as they try to help others. A large body of scholarship in the social sciences of disasters document that people faced with disasters and emergencies of all sorts become interdependent, cooperate, their actions taking into account the actions of others, restrained by the actions of others, so that in emergency evacuations they move together and assist each other. Social cohesion, a group level effect created by social relationships, or the extent to which people know others in the group, have established social relationships with others prior to the crisis, and have friends and other close personal relations in the group can be assumed to delay the collective decision to evacuate (Aguirre, Wenger, and Vigo, 1998) and to preserve the block effect during the evacuation movement. The lone actor and the free agent will decide to evacuate much more quickly than the social actor who is embedded in social relations, is concerned for others in the group, takes their opinions and interests into account before deciding when and what to do, and evacuate with the group.

Still in need of further research is the impact of group size and cohesion on the individual risk of fire fatality. Cornwell (2003) has shown, on the basis of information on the Beverly Hills Supper Club Fire of 1977, that group size and social cohesion increases this risk, but his findings are in need of replication and expansion, for they do not control for the differences among the groups to life threatening dangers, the resources of the groups' critical masses, and relevant differences in the built environment and the hazards precipitating the evacuation behavior.

As discussed previously, it is often the case than in the pre crisis situation groups are embedded in gatherings that take place during occasions, or culturally defined activities such as the 4th of July or going to work in the corporate work environment of the World Trade Center. When crises impact these gatherings, they transform the occasions; people then need to engage in symbolic interaction to develop new emergent definitions of the situation. New social relations and new norms or rules guiding behavior often take place within and among these groups as they fashion a collective response to the crisis. People exchange information, discuss alternatives, try to convince each other of what is going on, and eventually agree on what they must do to respond to the crisis. Importantly, the situation is such that it demands an individual and collective response; there is a sense of urgency. Once this emergent norm is created, members of the group that do not agree with it keep quiet out of fear of group censure, or are ignored by the group. Group members then try to convince people in other groups to adopt their new definition of what is going on, what needs to be done, and what is proper and necessary to do under the circumstances. Thus, as Goffman argued, it can be expected that there will be inter-group

proselytism and competition for hegemony in providing the master definition of the situation and what should be done to respond to it that will delay the evacuation response: the greater the initial diversity of definitions in the groups about what is happening and what should be done to respond to the crisis---to the extent that people are exposed to these competing alternatives---the longer it will take for people to make up their minds about what they should do (compare to Drury and Scott, 2001). Inter-group differences should also slow the evacuation movement in constrained spaces in which the groups cannot evade each other. Fire drills in high-rise buildings in which there are multiple firms in given floors and multiple firms in the building around which work groups form, would need to recognize the presence of inter-group competition, to make such drills more effective in establishing a master definition of what should be the appropriate evacuation behavior that everyone in the building will follow irrespective of group membership.

Groups also vary in the amount of resources available to them, and this variation will impact the start of evacuations. Paradoxically, our expectation is that the greater the amount of resources available to the groups, the slower will be their adoption of evacuation behavior, for it will take more time for the groups to agree on how to use these resources and integrate them into their new division of labor. Resources become items around which group dialogue ensues.

Perceptions of danger are socially determined. Dangerous conditions by themselves are not always effective triggers for evacuation response, except perhaps in situation of mass behavior previously identified, in which the evacuation response is forced upon the person. Instead, members of the group must interpret the situation as dangerous before they become a stimulus for collective action. Numerous studies of disasters indicate that there is a persistent and strong normalcy bias, in which people misunderstand the signs of dangers produced by the hazards and developing disasters and interpret them as normal features of daily routines. Such normalcy bias must be nullified before people will react to the crisis. Ambiguities and mixed messages and inaccurate interpretations of dangers often impact evacuation behavior, so that while it is true that the presence of inter subjectively verified and consistent signs of danger that are accurately perceived, such as smoking and loud sounds, facilitate the adoption of new behavior, this situation should not be assumed to be the normal state of affairs in simulation models. The current explosion of electronic communication technology facilitates a flood of information to would be evacuees that increases the ambiguity of the crisis situations, for these alternative sources of information often offer contrary alternatives to official information and directives and encourage a multiplicity of interpretations that impact decision making in emergency evacuations both at the individual and the group level. This is a problem that has received almost no research attention at present. Experimental results indicate that ambiguity facilitates suggestibility in crowds, and that suggestibility shortens the time to achieve consensus and facilitate the occurrence of more extreme consensus (Johnson and Feinberg, 1990). According to Leik and Gifford (1986) greater amounts of information increases the time needed to take protective action. Thus, it seems as if greater information has multiple and somewhat contradictory direct and indirect effects on decision making: a direct effect increasing the time needed for taking decisions, and indirectly increasing ambiguity which in turn increases suggestibility which shortens the time needed for taking decisions.

Human imagination, particularly how the actual or perceived physical incapacity of the actors, and the extent to which the physical tasks of evacuating present important challenges to them, impact their timing of evacuation behavior. People are able to imagine the physical demands of their response to the crisis and thus respond in terms of what they think they can do within the time and other considerations that they consider relevant as they formulate responses to the crisis. Thus, the elderly, the physically infirm, caretakers, women, the injured, will have a greater tendency to begin evacuating sooner than other categories of victims and will have a higher probability of becoming obstacles to the evacuation movement in constrained spaces. Signs of dangers such as smoke or fire are thus filtered through these personal attributes and impact both the decision to evacuate and the evacuation movement.

There is also a need to incorporate in simulation models more meaningful conceptions of leadership during the response to the crisis. Crisis contexts often neutralize pre existing norms and power arrangements in social organizations. The new situation demands new leadership skills. Moreover, it is also a fluid social organization, in which leadership is very often unstable and in which the procedures for the exertion of leadership are not established. In these crises contexts, persons that become leaders of the group are not necessarily those who conform to the norms of the group, since the normative system is in fact emerging. Nor are they necessarily the leaders of the group existing prior to the precipitating event. It is more likely the case that the member of the group that will become the leader is one that proposes an innovative solution to the collective problem that is judged plausible and credible by the other members of the group. Innovators will have a greater probability of being leaders in crisis situations with high uncertainty. Suggestively, Feinberg and Johnson's (1988) simulation study of crowds indicate that the agitator, or the person in the crowd with an extreme, innovative solution, is more likely to sway others in small gatherings, in highly ambiguous situations, and when others in the gathering trust her. Moreover, Johnson, Stemler and Hunter (1977; see also Johnson and Glover, 1978), in another experiment, showed that there is a shift to risk, in that collective decisions are on average more extreme than the sum of individual decisions about the same item. Presumably, group leaders will be more likely members of the critical mass, with the right skills and knowledge and the innovative ideas that are perceived as maximizing the chance of escape for everyone in the group.

It is worthwhile to conceptualize leadership in simulation models in terms of the keynoting process identified by Turner and Killian. In this sense the question of leadership reduces to the problem of what keynoting will be adopted by the group from the various suggestions that will be forthcoming as the group tries to determine a collective course of action to respond to the crisis. Such adoption is a symbolic process in which group members consider various alternative ways to respond and then explore the appropriateness of the alternatives. It is also impacted by the presence of culturally appropriate symbols of legitimate authority, such as uniforms and official looking paraphernalia, although the success of the keynoting by social control agents will depend on the extent to which their suggestions are in agreement with the basic values and perceptions of the group that they are trying to lead and with the emergent leadership in these groups. It is an interactive and not a unidirectional process; official directives are often ignored because of inaccurate understanding by the authorities of the priorities and needs of people (Stott and Reicher, 1998).

Conclusion

We have identified important social processes that impact emergency evacuations. Embedded in them are many worthwhile research questions still in need of answers, questions that assume the presence, in emergency evacuations, of heterogeneous actors that in their collective behavior act normatively and rationally. Studies of panic come to mind. The oldest view of panic assumed that people in dire emergencies lost their humanity and became animals overwhelmed by fear. A second view, sponsored by E. L. Quarantelli (1957) in the 1950s and 1960s, advanced a conceptualization of panic as a-social collective behavior. People did not become animals but rather attended to their own needs; they did not care for the fate of others. This view was replaced in the 1980s and 1990s by the work of Norris Johnson and other scholars (Keating, 1982) who pointed out that people did not panic, did not become animals, and did not abandon their ties to others. Instead, people in situations of great danger continued to be social actors embedded in social organizations. They continued to be deeply concerned for the fate of others so that they often imperiled their own lives on their behalf (compare to Helbing, Farkas and Vicsek, 2000; for an excellent review of theories of panic see Chertkoff and Kushigian, 1999). The assumption of heterogeneous actors acting rationally and normatively has a number of important implications that we have tried to identify. It has implications for the modeling of the direction of movement in simulations of emergency evacuation, which cannot be assumed to be unidirectional, since it is rational and normative and the product of symbolic interaction rather than the action of a herd or of robots. Rather, it is multidirectional, including people returning to the place they evacuated to help others, try to rescue friends, and salvage important belongings (Johnson, 1987; Johnson et al., 1994).

Simulation modeling of emergency evacuations has gone through three phases, flow, individual, and group (Low, 2000). Nowadays it is in the last two phases, in which simulation work begins to incorporate socio psychological and social organizational dynamics. The present day multiplicity of models of emergency evacuation, each with their own strengths and weaknesses, and without the appropriate methods of validation must be superseded by a government-sponsored effort to create a uniform simulation platform that would combine what is good in existing models, provide proper validation tools, and encourage multi disciplinary collaboration to advance them. That such effort is needed has been widely recognized. For example, Kuligowski's (2003) empirical analysis of EXIT89 and Simulex simulated a high-rise hotel building evacuation in which the same design elements were used, but yet reported "significant differences in egress times…EXIT89's evacuation times were found to be 25-40 % lower than Simulex for the design scenarios, attributed to differences in unimpeded speeds, movement algorithms, methods of simulating slow occupants, density in the stairs, and stair configuration input between the models…EXIT89 produced maximum evacuation times 30-40 % lower than Simulex."

Such wide disparity between two popular simulation programs could probably be duplicated with other models available nowadays, a potentially misleading situation that needs to be corrected.

In such context, research and theory in the social sciences can have an important effect in grounding the models in realistic assumptions regarding social behavior in crisis situations, and such modeling in turn could enrich our understanding of collective behavior in crisis situations. Simulation models of emergency evacuations can have enormous practical and scientific payoffs

not only for the social sciences but also for other sciences such as engineering and public health. However, simulation models can realize their full potential as a tool for emergency planning and intervention only if they are inextricably linked to fieldwork and empirical investigations of emergency evacuations that would provide computer scientists and mathematicians with the appropriate parameters for social behavior. Thus, their future is multi disciplinary, involving the expertise of computer scientists, engineers, fire scientists, social scientists, and emergency planners, among others.

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